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13. ABSTRACT *(Maximum 200 words)*

Understanding and predicting the snow conditions in snow terrain is important to the US Army in the transportation of military vehicles, equipment, and personnel and for monitoring battlefield environment in snow terrain. The snow parameters that characterize snow conditions are snow wetness, snow depth, snow density, and snow grain size and layering. These parameters describe the hydrological and mechanical states of the snow pack. Remote sensing of snow conditions using microwave and millimeters waves are useful techniques. The microwaves and millimeter waves interact with the snow rough surface and volume scattering to produce the bistatic and monostatic radar return.

Detection of mines in snow terrain environment is an important problem. The scattering of wave by the mine can be obscured by the scattering of snow clutter. A newly developed technique based on angular correlation function can be used to suppress the scattering by clutter and relatively enhance the scattering by the mine.

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Microwave and Millimeter Wave Remote Sensing of Snow and Detection of Buried Objects in Snow Environment

I. Statement of the Problem Studied

Understanding and predicting the snow conditions in snow terrain is important to the US Army in the transportation of military vehicles, equipment, and personnel and for monitoring battlefield environment in snow terrain. The snow parameters that characterize snow conditions are snow wetness, snow depth, snow density, and snow grain size and layering. These parameters describe the hydrological and mechanical states of the snow pack. Remote sensing of snow conditions using microwave and millimeters waves are useful techniques. The microwaves and millimeter waves interact with the snow rough surface and volume scattering to produce the bistatic and monostatic radar return.

Detection of mines in snow terrain environment is an important problem. The scattering of wave by the mine can be obscured by the scattering of snow clutter. A newly developed technique based on angular correlation function can be used to suppress the scattering by clutter and relatively enhance the scattering by the mine.

II. Summary of the Most Important Results

1. Rough Surface Scattering

Monte Carlo simulations give exact solutions of Maxwell's equations given the rough surface height profiles. For the past few years, we have systematically developed a new methodology for solving the integral equation for 2-D random rough surfaces [1-2]. The method saves tremendously both CPU and computer memory. The method is termed the Sparse-Matrix Canonical-Grid Method (SMCG). It decomposes the integral equation matrix into a sparse matrix which represents strong interaction and the remainder of the matrix represents the weak interaction part. The weak part of the matrix is conveniently rewritten in a Taylor series by expanding Green's function about a flat surface. SMCG allows us to solve a 32 wavelength by 32 wavelength surface with 131072 surface unknowns. The approach has given exact solution of Maxwell's equation for 2-dimensional surface. This approach gives an exact solutions of Maxwell's equations and gives results that compare well with laboratory experimental data of 2-dimensional random rough surfaces (Figure 1). Exact solutions avoid the restrictions of classical analytic methods that are limited in regime of validity of frequency, rough surface conditions and incident angles. The method was recently extended to 2-dimensional dielectric surface.

2. Volume Scattering in Snow

According to classical theory, the behavior of a wave through an ensemble of particles can be determined by considering the propagation characteristics of a single particle. However, when considering a dense random medium (i.e., the case where the scatterers occupy a significant fraction of the volume) like the ice grains in snow, the mutual interaction between particles must be considered. The correlation of particle positions due to dense packing also gives a relative phase relationship between scattered waves from different particles. The dense media analytic theories show that correlated scattering of different ice grains are important. The pair distribution functions of relative particle positions affects the correlated scattering effects. Another method that we have used to examine wave propagation and scattering by random discrete scatterers is Monte Carlo simulations.

Figure 2 shows a portion of a snow section from a site in Fairbanks, Alaska prepared at the Army Cold Regions Research Engineering Laboratory (CRREL) in Hanover, New Hampshire [3]. The 2-D subsections were prepared by first casting the snow and then slicing, polishing, and dyeing so the snow grains are visible against the pore space.

3. Detection of Buried Object

An important key element in the detection of mine under snow is how to discriminate scattering of electromagnetic waves by mines from unwanted snow clutter. Our work is centered on a novel detection technique that was recently developed based on new angular correlation phenomena, called the "memory effect". By choosing the appropriate set of incident and scattered angles, results show that for cases when scattering intensities of clutter and buried object are comparable, the angular correlation function of the deterministic object can be many dB higher than that of clutter. An advantage of the technique, is that, unlike tomography or classical inverse scattering problem, very few incident and scattered angles are needed, and therefore, the system will be much simpler and lower cost than tomographic or other techniques.

If the configuration of the transmitters and receivers are away from the memory line, then the contribution from clutter scattering is minimized and the scattering by the buried object is enhanced relatively by many dB. This has been verified in laboratory experiments [6] and numerical simulations [5,7].

To illustrate the method, a simple configuration of using two monostatic radars for measurement of ACF of wave scattering by a buried object below a random rough surface is shown in figure 3. An example of the results of ACF are shown in figure 4. The "+" represent in dB the ratio of the intensity with mine and the intensity without the mine. The "o" represent in dB the ratio of ACF with mine and the ACF without mine. The results show that the ACF ratios are consistently up to 15 dB higher than the ratios of intensities. This illustrates that ACF is a useful technique for detecting the mine in snow clutter environment and is superior to that of intensity. Besides the configuration of two monostatic radars, other bistatic arrangements are possible.

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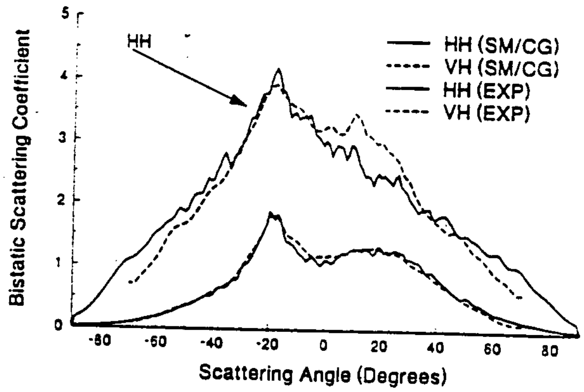

Figure 1: *Comparison between numerical simulation and millimeter wave experimental data. Parameters are: incident angle $\theta_i = 20°$, $\phi_i = 0°$ (plane of incidence), rough surface rms height $= 0.5\lambda$ correlation length $= 2.0\lambda$*

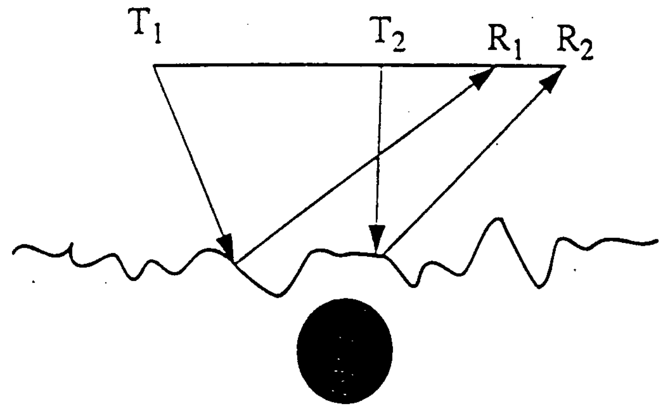

Figure 3: *Transmitters T_1, T_2 and receivers R_1, R_2 are mounted on a rod attached to vehicles. Mine is buried under rough surfaces.*

Figure 2: *Snow section from Fairbanks Alaska, March 3, 1993*

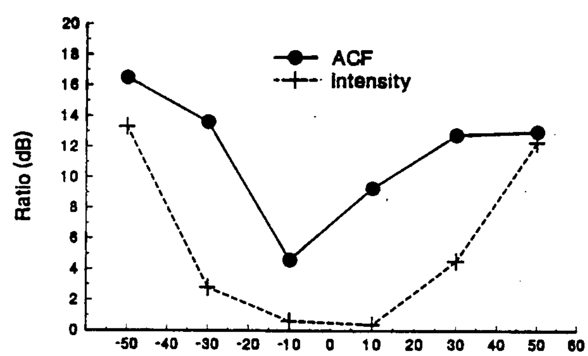

Figure 4: *The x-axis denotes the incident angle for θ_{i2} (degree). o represents the ratio of ACF with mine and ACF without mine. + represents the ratio of intensity with mine and without mine.*

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